An assessment of the information content of South African alien species databases

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National alien species databases indicate the state of a country's biodiversity and provide useful data for research on invasion biology and the management of invasions. In South Africa there are several different published alien species databases, but these databases were created for different purposes and vary in completeness and information content. We assessed the information content of published South African alien species databases in the context of other such databases globally, and evaluated how the information content of South African databases varies across taxonomic groups. Although introduction pathway, date of introduction, region of origin and current broad-scale distribution data are available for most taxonomic groups assessed (60% – 90%), data on invasion status, introduction effort and introduction source are available for few taxonomic groups (5% – 18%). South African alien species databases have lower information content than the detailed databases available in other parts of the world and thus cannot be utilised to the same extent. We conclude with 11 recommendations for improving South African alien species databases. In particular, we highlight the data types that should be incorporated in future databases and argue that existing data should be collated in a single, standardised meta-database to facilitate cross-taxon comparisons, highlight gaps in effort, and inform managers and policy makers concerned with alien species.

Introduction

Humans are introducing species to regions beyond their native range; however, few of these species become invasive and have deleterious impacts (Blackburn *et al.* 2011). National lists of alien species provide the taxonomic identities of introduced species. These data are required to assess the current state of biodiversity; for example, they are used to measure progress towards meeting the Convention on Biological Diversity's (CBD) Strategic Plan for Biodiversity (2011–2020) Aichi target 9 (Butchart *et al.* 2010; McGeoch *et al.* 2010, 2012; UNEP 2011). Alien species databases contain much more data than a simple list of introduced species. The valuable data stored in these databases (e.g. on pathways and dates of introduction, distribution and invasion success) can be used to inform the management of invasions and further our understanding of biological invasions (Table 1) (also see Cadotte, Murray & Lovett-Doust 2006; Pyšek *et al.* 2012). For example, alien species databases are a data source for research on the predictors of invasion success, pathways of introduction and species distribution modelling. Such research underpins invasive species risk assessments and aids in the prioritisation of species, pathways and areas for surveillance and management.

The documented knowledge of introduced organisms varies greatly across countries (Pyšek *et al.* 2008). Although some databases provide minimal data others are quite detailed. For example, an alien plant catalogue for the Czech Republic provides 13 fields of data on 1454 species (Pyšek *et al.* 2012; Pyšek, Sádlo & Mandák 2002). The data provided in this Czech catalogue have been used in studies covering many topics, including range filling, associations with pollinators and the interaction of traits (Pyšek *et al.* 2012). In contrast, databases that lack detail, or that are incomplete or poorly contextualised, pose a biosecurity risk and may reduce management effectiveness and research quality and scope (McGeoch *et al.* 2012; Pyšek 2003). Moreover, global research effort on alien species (Pyšek *et al.* 2008) and alien species databases (Crall *et al.* 2006; Ricciardi *et al.* 2000) are taxonomically biased.

The consequences of inadequate databases and taxonomically biased data can be averted through the identification of data gaps and efforts made to alleviate the detected disparities. However, increasing the amount of data does not necessarily lead to an equal increase in benefits for research, decision making and management (Grantham *et al.* 2008; Pyšek *et al.* 2008; Simberloff 2003). For example, detailed data (e.g. on population biology) is often not required to eradicate recently introduced species, but may be vital for the management of established alien species

TABLE 1: Research questions or topics that can be addressed using the data in alien species databases, the usefulness of each question or topic for management or policy, the types of data provided by alien species databases required to address each question and examples from literature.

Research question	Use for management or policy	Data required	Examples
What are the determinants of invasion success?	Informs pre- and post-border risk assessment.	Taxonomic identity, invasion status, pathway and date of introduction, biological trait data, introduction effort, introduction source and origin and other potential predictors of invasion success.	Dawson, Burslem & Hulme (2009); Pyšek, Jarošík & Pergl (2011); Williamson (2006)
How accurate are risk assessments?	Indicates risk assessment performance.	Taxonomic identity, invasion status, failure.	Reichard & Hamilton (1997)
What traits are related to invasion status?	Informs pre- and post-border risk assessment.	Taxonomic identity, invasion status, biological trait data.	Kolar & Lodge (2002)
What are the important pathways of introduction?	Informs prevention strategies (e.g. inspection strategies). Required to meet Convention on Biological Diversity (CBD) goals.	Taxonomic identity, pathway of introduction.	Gollasch & Nehring (2006); Kenis *et al.* (2007); Pyšek, Jarošík & Pergl (2011)
Have the pathways of introduction changed temporally?	Informs prevention strategies (e.g. inspection strategies).	Taxonomic identity, pathway and date of introduction.	Genovesi *et al.* (2012); Pyšek, Jarošík & Pergl (2011)
How have introductions or invasions changed over time?	Required to measure progress towards CBD goals.	Taxonomic identity, date of introduction, invasion success.	Gollasch & Nehring (2006); McGeoch *et al.* (2010)
How many and what type of organisms may be introduced in the future?	Informs prevention strategies (e.g. inspection strategies).	Taxonomic identity, date of introduction.	Levine & D'Antonio (2003)
Are introduced species non-random (e.g. with regards region of origin, source regions or taxonomy)?	Informs prevention strategies (e.g. inspection strategies).	Taxonomic identity, region of origin and/or source region.	Gollasch & Nehring (2006); Kenis *et al.* (2007); Richardson & Rejmánek (2004)
Does the level of invasion or invasiblity vary spatially?	Informs early detection and eradication strategies.	Distribution data.	Chytrý *et al.* (2008)
What factors affect the current distribution and future dispersal of alien species?	Informs early detection and eradication strategies, as well as distribution modelling.	Distribution data, biological traits, records of introductions, dispersal pathways.	Williamson *et al.* (2005)
What is the potential distribution and spatio-temporal spread of an alien species?	Informs risk assessment as well as early detection and eradication strategies.	Current distribution data, date of collection data.	Jarnevich *et al.* (2010); Rouget *et al.* (2004); Smolik *et al.* (2010)

Note: Please see the full reference list of the article, Faulkner, K.T., Spear, D., Robertson, M.P., Rouget, M. & Wilson, J.R.U., 2015, 'An assessment of the information content of South African alien species databases', *Bothalia* 45(1), Art. #1103, 11 pages. http://dx.doi.org/10.4102/abc.v45i1.1103, for more information.

(Simberloff 2003). Additionally, comprehensive data on a limited number of species is often sufficient to generalise and develop theories on biological invasions (Pyšek *et al.* 2008). Thus, although the data contained in detailed alien species databases is valuable, the types and amount of data required will depend on the research question or management strategy (Table 1).

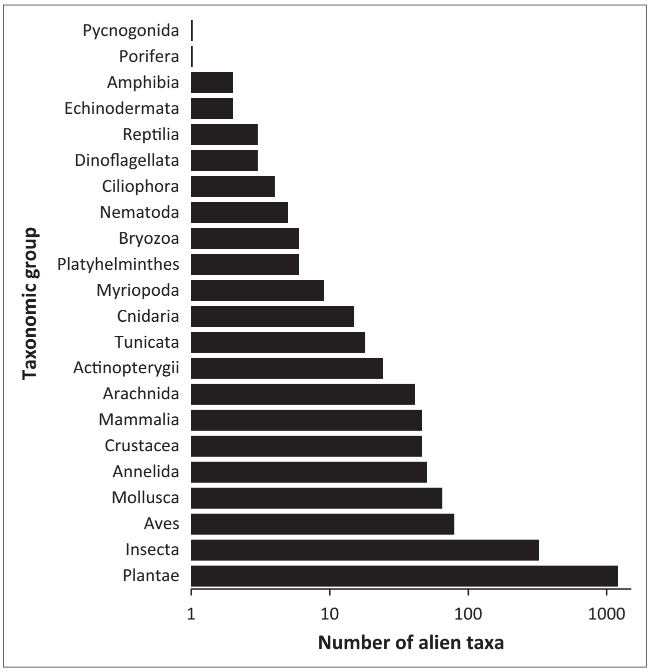
South Africa has a large number of alien species from a wide variety of taxonomic groups, including the Insecta, Mammalia, Mollusca and Plantae (Henderson 2001; Herbert 2010; Picker & Griffiths 2011; Van Rensburg *et al.* 2011). For many taxonomic groups recent alien species databases are available, some of which provide many types of data. However, these databases were developed for different purposes and vary in information content. Consequently, it is unknown whether South African alien species databases can be used to the same extent as the detailed databases in other countries. We aimed to assess the overall information content of South African alien species databases in terms of introduction (dates, pathways, effort and source), region of origin, distribution and invasion status (current status and failure). We explore how the information content of these databases varies across taxonomic groups. Finally, we identify knowledge gaps and suggest key areas for future work.

Methods

Database identification

Alien species databases published up until December 2012 in peer-reviewed papers, books and reports were identified and assessed. A large number of databases pertain to South African alien species, but many are either poorly integrated or do not focus entirely on alien species. Therefore, we obtained a sample that was of a manageable size and that was representative of all taxonomic groups. These databases were identified using expert opinion and by consulting the references of previously assessed publications. We only assessed databases developed for a national level or databases developed for a regional or global level from which national level data could be extracted. Although comprehensive lists of alien Reptilia in captivity (Van Wilgen *et al.* 2010) and Plantae under cultivation (Glen 2002) are available, lists of species in the introduction stage of the invasion continuum (Blackburn *et al.* 2011) are not available for many other taxonomic groups. Furthermore, many of the data types assessed here (e.g. distribution data) are not applicable for species that have not yet spread outside of captivity or cultivation. Thus databases of species in captivity or under cultivation were not evaluated. A total of 34 alien species databases spanning 23 taxonomic groups were assessed, such that an indication of the number of alien taxa and the data content housed in each database was obtained (Tables A1 & A2).

For each taxonomic group we selected (from the sample of 34 databases) recent databases (2000–2012) that list a high number of alien taxa and that provide numerous types of data (Tables A1 & A2). We focussed on more recent alien species databases as such databases collate and update the data found in previous inventories, and should incorporate more recent taxonomic revisions. Additionally, for taxonomic groups that occur in a range of environments (e.g. Mollusca and Crustacea), care was taken to ensure that the selected databases spanned the various environments inhabited (Table A2). Consequently for some groups, databases that list few species but focus on a specific environment were included. For example, Insecta that are associated with the intertidal zone are discussed in a paper by Mead *et al.* (2011) on estuarine and marine taxa (Table A2). For taxonomic groups for which multiple, recent alien species databases exist, we used expert opinion to further confirm our selection. For each taxonomic group (i.e. marine invertebrate groups [e.g. Tunicata], Plantae, Aves, Reptilia, Crustacea, Insecta, Actinopterygii [ray-finned fishes], Mollusca and Mammalia), at least one South African expert that has worked on alien species listing was contacted. Each expert was asked to identify, for the taxonomic group of interest, the published alien species database that is currently the most comprehensive with regards to both the listed taxa and information content. Based on the opinion of these experts, two databases (i.e. De Moor & Bruton 1988 and Germishuizen *et al*. 2006) were added to our selection as they currently contain the most recent, comprehensive lists available for the Actinopterygii and Plantae – despite De Moor and Bruton (1988) being published before 2000. Finally, as an updated version of Germishuizen *et al.* (2006) is available online (http://posa.sanbi.org), this online database was used in the full analysis. In total, 14 databases spanning 23 taxonomic groups were selected for the full analysis (Tables A1 & A2).



Note: Pycnogonida (sea spiders), Porifera (sponges), Echinodermata (e.g. star fish and sea urchins), Nematoda (round worms), Bryozoa (moss animals), Platyhelminthes (flat worms), Myriopoda (e.g. centipedes), Cnidaria (e.g. jelly fish), Tunicata (ascidians), Actinoptergii (ray-finned fishes), Annelida (e.g. earthworms), Aves (birds).

FIGURE 1: The number of alien taxa listed for each taxonomic group in the selected alien species databases and included in the analysis.

Data extraction

Data on taxon name and taxonomic group were extracted from the 14 selected alien species databases. Taxa were assigned to taxonomic groups based on the taxonomy used by the selected databases. Although such definitions may influence results and lead to groupings at various taxonomic levels, these groupings reflect the taxonomic levels at which alien taxa are often listed and managed.

Taxa listed that are translocated indigenous species (e.g. the Mozambique tilapia *Oreochromis mossambicus*; see Van Rensburg *et al*. 2011), suspected to be indigenous or listed as 'dubious records' (e.g. the mollusc *Vertigo antivertigo*, which has been found only as a subfossil; see Herbert 2010) were not included in the analysis. As the listing of species in captivity or under cultivation is not comprehensive, any species listed that has entered the country but is not found outside of captivity or cultivation was excluded from the analysis. Furthermore, the Brachiopoda, one of the 23 taxonomic groups included in the selected databases, were not included in the analysis as the only introduced species, *Discinisca tenuis*, is found exclusively within aquaculture facilities (Mead *et al.* 2011).

Although for each taxonomic group recent alien species databases that list many species were utilised to develop the resultant list of taxa (Figure 1), there may be alien taxa in South Africa, besides those discussed in the paragraph above, that have been excluded. Such exclusions may be a result of listing errors (McGeoch *et al.* 2012) or the rapid rate at which new species are introduced. However, the aim of this work was not to create a comprehensive list of South African alien taxa but rather to assess the data provided by a representative sample of existing alien species databases. Additionally, our aim can be achieved by using a representative list that contains a large proportion of South African alien taxa.

Date of introduction, pathway of introduction, region of origin, distribution and invasion status data were extracted from the selected alien species databases (Table 2). Notes were also taken on whether data on introduction source (region from which the organism was introduced), introduction effort (number of individuals introduced and/or introduction events) and failure (taxa that failed to establish) were provided (Table 2). Approximate dates of introduction or regions of origin (e.g. continent) and distribution data in descriptive form or point distribution maps were included as available data (Table 2). Invasion status data were only deemed available if the invasion status of the organism as per Richardson *et al.* (2000) or Blackburn *et al.* (2011) was stated or the category of the taxon under legislation – Conservation of Agricultural Resources Act (CARA) and National Environmental Management Biodiversity Act (NEMBA) – was specified (Table 2). Although various invasion status classifications exist, the classifications of Richardson *et al.* (2000) and Blackburn *et al.* (2011) were employed as they are used internationally (e.g. Pyšek *et al.* 2012) and as the classification of Blackburn *et al.* (2011) is applicable to all taxa. These classifications divide the invasion continuum into four stages: transport, introduction, establishment and spread (Blackburn *et al.* 2011; Richardson *et al.* 2000). Based on the invasion stage occupied, an organism's invasion status is classified as (1) introduced or casual, (2) naturalised or established and (3) invasive (Blackburn *et al.* 2011;

TABLE 2: Categories of information content used in the analysis of the South African alien species databases and ranked value.

Category	Units	Example	Rank†
Pathway of introduction	Description of how the organism was introduced	'ship fouling or ballast water'	1
	Description of why the organism was introduced	'biological control agent'	1
Date of introduction	Year of introduction	'1930'	1
	Year of first record	'1940'	2
	Period of time	'1930–1940', 'early 1980s'	3
	Approximate year of introduction	'~1833'	2
Introduction effort	The number of introduction events	-	1
	Years of introduction events	'1920, 1930'	2
	The number of introduced individuals	-	1
	Indication that there has been multiple introduction events	'additional introduction events after first known introduction date'	3
Introduction source	Name of country	'Scotland'	1
Region of origin	Name of continent or ocean	'North America', 'Pacific'	4
	Name of region	'West Africa'	3
	Name of country	'Argentina'	2
	Name of place	'Amazon'	1
Distribution	Point distribution maps	-	1
	Descriptions	'Widespread', 'Western and Eastern Cape', 'Single site record at Durban'	2
Invasion status	Status as per Richardson *et al.* (2000) and Blackburn *et al.* (2011)	'Casual'/'Not Established', 'Established'/'Naturalised', 'Invasive'	1
	CARA or NEMBA category provided	'Declared invader (category 2)'	2
Failure	Inclusion of taxa with descriptions of current status that indicate a failure to establish	'Possibly extinct, failed to establish', 'Extinct'	1

†, A value of 1 represents a high ranking.

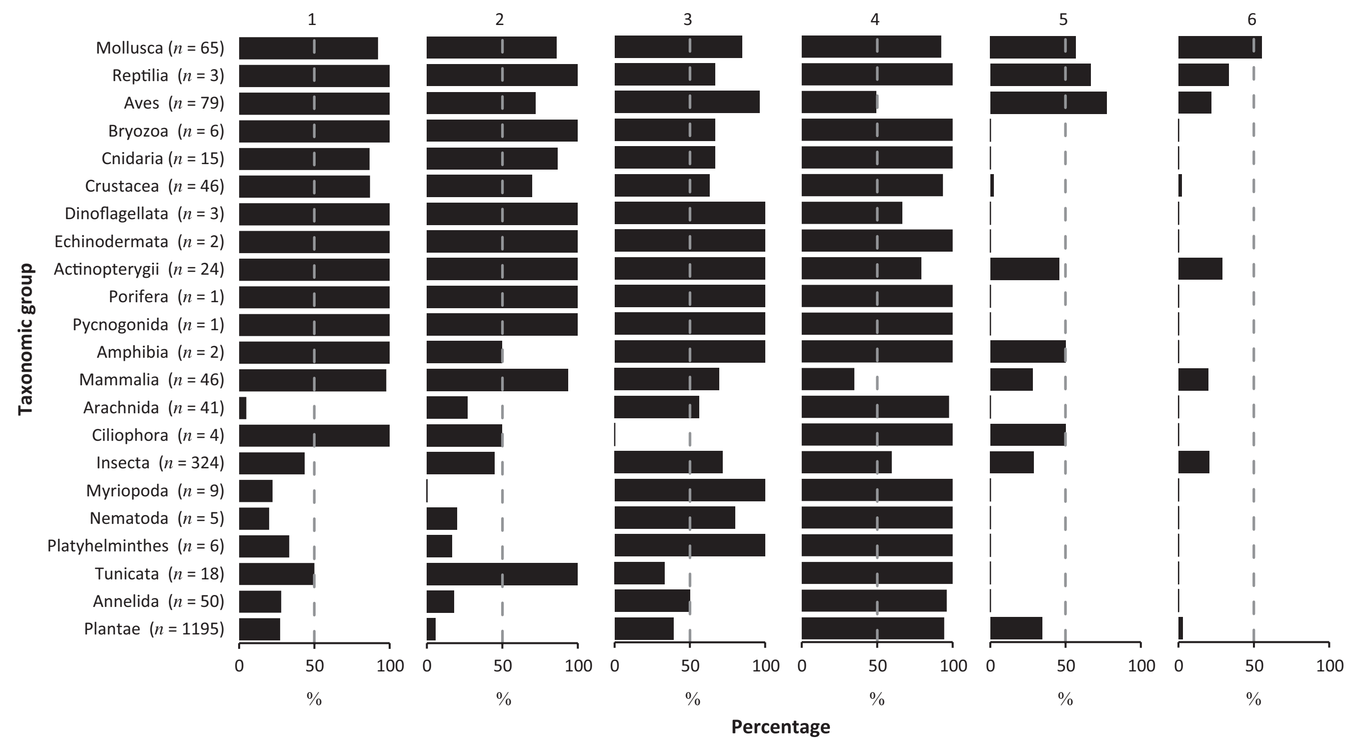


FIGURE 2: Percentage of the total number of alien taxa per taxonomic group for which data on (1) pathway of introduction, (2) date of introduction, (3) region of origin, (4) distribution, (5) invasion status and (6) all the aforementioned categories were provided. The number of species in each taxonomic group is given in round brackets and taxonomic groups are arranged according to descending data comprehensiveness (i.e. the number of categories for which data is available for greater than 50% of taxa).

Richardson *et al.* 2000). Data were classified as unavailable if either no data were available or the characteristics were listed as 'unknown'. The information content of the selected alien species databases for each taxonomic group was determined by calculating the total number of alien taxa in each taxonomic group (Figure 1), and determining the percentage of taxa in each group for which the data of interest were provided. Results were plotted in R version 3.0.0 (R Core Team 2013).

Results

For the majority of the taxonomic groups, pathway (64% of taxonomic groups) and date of introduction data (59% of taxonomic groups) are available for over 50% of taxa (Figure 2). These introduction data are available for a large proportion of the vertebrate and invertebrate groups (Figure 2). However, the availability of both pathway and date of introduction data are poor for the two taxonomic groups with the greatest number of recorded taxa, namely the Plantae and Insecta (Figure 2). The availability of other introduction data, in general, is poor and introduction source data are only available for the Actinopterygii, whereas introduction effort data are available for the Aves, Actinopterygii, Mammalia and Reptilia.

Data on region of origin are available for a large proportion (50% or greater) of taxa from all taxonomic groups except the Plantae, Tunicata and Ciliophora – that is, 82% of taxonomic groups (Figure 2). For the majority of taxonomic groups, these data are available at a continental scale (Table 2).

Distribution data are available for over 50% of the taxa from all taxonomic groups except the Mammalia – that is, 91% of taxonomic groups (Figure 2). For most taxa these data are in a descriptive form and point data are only available for the terrestrial Mollusca and some introduced Plantae (Table 2).

Invasion status data are not available for most taxonomic groups (86%), with the exception of the Aves, Reptilia and Mollusca, for which these data are available for more than 50% of taxa (Figure 2). When all taxonomic groups are considered, invasion status data are available for 33% (633 of 1945) of taxa. For those taxa for which invasion status data are available, 14% (88 of 633) were classified as introduced or casual, 23% (145 of 633) as established and 63% (400 of 633) as invasive. Data on introductions that failed to establish are only available for the Actinopterygii (4 taxa), Aves (52 taxa), Mammalia (1 taxon) and Insecta (23 taxa released as biological control agents).

Across the taxonomic groups few taxa (172 taxa or 9%) had data available for all data categories (Figure 2). Additionally, for only one taxonomic group (Mollusca) data for all categories are available for the majority of taxa (Figure 2). No data are available for 8% of the introduced Insecta. However, across taxonomic groups, data for at least one data category are available for 98% of introduced taxa. Therefore, the level of data provided by South African alien species databases is high for some taxonomic groups (e.g. Mollusca, Reptilia, Aves, Crustacea and some marine invertebrate groups), but low for others (e.g. Plantae and Insecta) (Figure 2).

Discussion

The information content of South African alien species databases varies taxonomically and based on the type of data assessed. Although only 10% of countries have adequate invasive species data (McGeoch *et al.* 2012), the information content of South African alien species databases is less than that of the alien species databases of other nations. For example, less data (pathway of introduction, date of introduction, region of origin and current broad-scale distribution) are available for alien taxa in South Africa in comparison to data available for organisms in Europe (Genovesi *et al.* 2012; Kenis *et al.* 2007; Pyšek *et al.* 2012), for vertebrates in Brazil (Rocha, Bergallo & Mazzoni 2011) and for Plantae in Chile (Ugarte *et al.* 2011). However, although the availability of invasion status data in South Africa is poor in comparison to some nations – for example, alien Plantae of the Czech Republic (Pyšek *et al.* 2012) and New Zealand (Howell & Sawyer 2006) – it is similar to the availability of these data in other countries – for example, aquatic species in Germany (Gollasch & Nehring 2006).

Consequently, the degree to which South African alien species databases can be used for research and management varies across taxa and depends on the type of data required (Table 1). For instance, pathway of introduction analyses, work on the predictors of invasion success and distribution modelling are possible for the Mollusca, and pathway analyses are feasible for Aves (Table 1). However, as they currently stand, even the most detailed South African alien species databases cannot be utilised to the same degree as the detailed catalogues that are available in other parts of the world. For example, South African alien species databases cannot be used to tackle the wide range of research topics – for example, species invasiveness, habitat invasibility and rates of spread (Table 1) – that have been addressed using the alien plant catalogues of the Czech Republic (Pyšek *et al.* 2012).

The data gaps identified here may be attributed to two main sources, namely a lack of data and data inaccessibility (McGeoch *et al.* 2012). A lack of data may be ascribed to difficulty recording and collecting data on some organisms. For example, data on intentional introductions (e.g. pathway and date of introduction) may be more easily recorded than for unintentional introductions (Lehan *et al.* 2013). However, as shown here, the data available for taxonomic groups that are often introduced accidentally (e.g. Mollusca and Crustacea) are comparable to the data available for organisms that are often introduced intentionally (e.g. Aves and Reptilia). Moreover, the relatively poor data available for the Plantae and Insecta may be ascribed to difficulties in collecting, recording and maintaining data for a large number of organisms. A lack of data can be remedied by directed action. For example, the MammalMAP project will improve distribution data for African Mammalia, including aliens (T. Hoffman [Animal Demography Unit, University of Cape Town] pers. comm., 20 February 2013). Data inaccessibility is a consequence of unpublished or diffused data and of data not always being accessible electronically (McGeoch *et al.* 2012). For instance, distribution data for alien Aves are available through the Southern African Bird Atlas Programme (SABAP) but have not been included in alien species databases. Additionally, although the Southern African Plant Invaders Atlas (SAPIA) is an important source of data, this atlas has not been printed in hard-copy since 2001 and, because of technical issues with the website, the online version of these data has not been updated since 2007 (L. Henderson [Agricultural Research Council, Plant Protection Research Institute] pers. comm., 08 May 2013). These data availability problems are not unique (Crall *et al.* 2006; Ricciardi *et al.* 2000), for example only 43% of invasive species databases in the USA are available online (Crall *et al.* 2006).

BOX 1: Recommendations on how South African alien species databases can be improved.

1. Future databases should include data on species name, synonyms, family, date of introduction, pathway of introduction (which could be classified according to Hulme *et al.* (2008) as release, escape, contaminant, stowaway, corridor and unaided), introduction effort, point of introduction, introduction source, region of origin, date of last record, distribution, invasion status, impact and biological data. The collation of such data for individual species would require considerable effort, numerous data sources and consultation with experts.
2. Further surveys, particularly focusing on poorly surveyed organisms, for example soil organisms and other invertebrates (see Spear *et al.* 2011), should be undertaken and more taxonomists should be trained and funded (Pyšek *et al.* 2013). Such targeted investments often lead to a large increase in the number of recorded alien taxa (Hulme *et al.* 2009b; Mead *et al.* 2011). Additionally, sampling should be focussed on introduction hotspots, for example, harbours for marine organisms (Griffiths, Robinson & Mead 2009).
3. Lists of alien taxa in captivity or under cultivation need to be collated. Such lists are vital to prevent introductions through escapes. The collation of these lists would require information from various sources, for example, lists of terrestrial vertebrates kept in zoos (Spear & Chown 2008, 2009), Actinopterygii in aquaria stores (Semmens *et al.* 2004), vertebrates in pet stores and Plantae in nurseries (see Van Wilgen *et al*. 2010).
4. Standardised, internationally recognised terminologies and definitions must be utilised. For the purpose of invasion status designations we recommend the framework of Blackburn *et al.* (2011). This scheme is applicable across taxa, although the categories might need additional interpretation for particular groups (e.g. Wilson *et al.* 2014 for introduced trees). For recording current environmental impact we recommend another recent scheme by Blackburn *et al*. (2014).
5. The metadata for databases need to state the purpose for which the database was developed.
6. Estimates of the effort taken in constructing the databases are needed. For example, which areas of the country were sampled and with what intensity. Additionally, information on the sources of additional data and the effort expended to identify these sources would be useful.
7. Estimates of the error rates in existing databases (e.g. the number of taxonomic misidentifications) are difficult to measure, but crucial if the databases are to be used with confidence, and can have important consequences for management (Paterson *et al.* 2011; Pyšek *et al.* 2013). Updated databases could report errors made in previous versions and justifications for changes could be provided (e.g. Pyšek *et al.* 2012).
8. Existing expertise should be utilised. This could be facilitated through the use of an expertise registry that is regularly updated (e.g. Musil & Macdonald 2007).
9. Taxonomies must be standardised and synonymies avoided. For example, for the Plantae the Angiosperm Phylogeny Group (e.g. APG 2009) can be used to standardise the taxonomy of angiosperm species. See www.theplantlist.org for accepted nomenclature.
10. Data from different sources need to be collated, shared and published (Crall *et al.* 2006). Various unpublished sources of data exist and to identify these sources the assistance of many experts would be required.
11. Finally, a single meta-database should be developed for the purpose of housing data on all South African alien taxa (see the Conclusion for details).

Lists of alien species suffer from a wide variety of errors (McGeoch *et al.* 2012), and any inaccuracies in the taxonomic data contained in the utilised databases would have influenced our conclusions (Pyšek *et al.* 2013). Alien plants and vertebrates in South Africa are relatively well studied (Richardson *et al.* 2003); in contrast, as a result of inadequate sampling and poor taxonomic knowledge, data on invertebrates are inadequate (Griffiths, Robinson & Mead 2009; Picker & Griffiths 2011; Richardson *et al.* 2011). These taxonomic biases may be a result of research needs (plants dominate the alien species pool), the ease with which plants may be recorded and studied (Crall *et al.* 2006; Pyšek *et al.* 2008), and the high degree of human assistance required for vertebrate introductions (Van Rensburg *et al.* 2011; Vitousek *et al.* 1996). As a consequence, the taxonomic data and related alien species richness estimates for plants and vertebrates may be more reliable than that available for invertebrates. However, determining the number and identity of introduced taxa in a region is difficult and differing definitions, methodologies or years of assessment can lead to disparate results (Bastos *et al.* 2011; Pyšek *et al.* 2004; Vitousek *et al.* 1996).

Finally, a wide range of alien and invasive species definitions exist and the use of disparate definitions may lead to listing differences and confusion (McGeoch *et al.* 2012; Richardson *et al.* 2000). In this assessment we only included invasion status designations made using the terminologies of Richardson *et al.* (2000) and Blackburn *et al.* (2011). Thus the inclusion of other terminologies and definitions may have increased the number of taxa (particularly for the Plantae) for which invasion status data are available (Richardson *et al.* 2000). For example, SAPIA designates species into categories that include transformer weeds, special effect weeds and ruderal weeds. However, the classifications of Richardson *et al.* (2000) and Blackburn *et al.* (2011) are utilised internationally and it is vital for research and management that such standardised and recognised terminologies and classifications are employed (Pyšek *et al.* 2004).

Conclusion

We conclude with 11 recommendations for improving South African alien species databases in Box 1. We argue that the last recommendation (that of creating a meta-database) is currently the highest priority. A meta-database should have a standard format that would facilitate analyses within and across taxonomic groups. Currently, the wide variety of data formats in use makes these analyses difficult. The database would potentially resolve issues of accessibility, and could be formally published periodically (Cadotte, Murray & Lovett-Doust 2006; Pyšek, Sádlo & Mandák 2002; Pyšek *et al*. 2012). A database such as this, which can be rapidly updated, would better manage the rapidly changing nature of alien species data. The database could include known failed introductions, hybrids and taxa in captivity or under cultivation. Additionally, invasive alien taxa that pose an introduction risk because of their presence in neighbouring countries could be included (Hulme *et al.* 2009a). As it would work across different databases, data quality checks could be developed (Crall *et al.* 2006) and independent reviews would be easier to undertake (Hulme *et al.* 2009a). These checks could focus on the various errors that may influence the data quality of alien species databases (McGeoch *et al.* 2012) and which in turn affect the management and research that rely on these data (Crall *et al.* 2006; Pyšek 2003). We believe that trying to combine databases into a single meta-database will help resolve, or at least highlight, many of the gaps in our knowledge of alien species in South Africa, and will certainly help work towards regular, detailed biodiversity assessments.

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Competing interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

Authors' contributions

K.T.F. (South African National Biodiversity Institute), and D.S. (South African National Biodiversity Institute) collected the data. K.T.F. analysed the data. K.T.F., D.S., M.P.R. (University of Pretoria), M.R. (University of KwaZulu-Natal) and J.R.U.W. (South African National Biodiversity Institute) wrote the manuscript.

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Appendix 1

TABLE A1: Assessed alien species databases.

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Note: Only references that appear in bold font were included in the full analysis.

TABLE A2: Results of the assessment of alien species databases.

Taxonomic group	Reference	Type	Year	Region	Habitat	# Taxa	# Categories	Path	Date	Origin	Distribution	Status	Failure	Effort
Actinopterygii	Bruton & Merron (1985)	r	1985	sthrn A	f	20	3	Yes	No	No	No	Yes	Yes	No
Actinopterygii	Bruton & Van As (1986)	b	1986	SA	f	20	2	No	Yes	No	Yes	No	No	No
Actinopterygii	***De Moor & Bruton (1988)**	**r**	**1988**	**sthrn A**	**f**	**21**	**7**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Actinopterygii	**Mead *et al*. (2011)**	**jp**	**2011**	**SA**	**m**	**1**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Actinopterygii	**Van Rensburg *et al*. (2011)**	**b**	**2011**	**SA**	**f**	**15**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**
Actinopterygii	**Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**f**	**18**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Amphibia	**Van Rensburg *et al*. (2011)**	**b**	**2011**	**SA**	**t & f**	**2**	**6**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**
Annelida	**Plisko (2010)**	**jp**	**2010**	**SA**	**t**	**50**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Annelida	**Mead *et al*. (2011)**	**jp**	**2011**	**SA**	**m**	**10**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Annelida	**Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t & m**	**48**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Arachnida	**Dippenaar-Schoeman & Harvey (2000)**	**jp**	**2000**	**SA**	**t**	**1**	**1**	**No**	**No**	**No**	**Yes**	**No**	**No**	**No**
Arachnida	**Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t**	**40**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Aves	Long (1981)	b	1981	g	t & f	18	6	Yes	Yes	Yes	Yes	No	Yes	Yes
Aves	Bruton & Merron (1985)	r	1985	sthrn A	f	5	1	Yes	No	No	No	No	No	No
Aves	Deacon (1986)	b	1986	SA	t	1	1	No	Yes	No	No	No	No	No
Aves	Bruton & Van As (1986)	b	1986	SA	f	5	0	No	No	No	No	No	No	No
Aves	De Moor & Bruton (1988)	r	1988	sthrn A	f	2	7	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Aves	**Dean (2000)**	**jp**	**2000**	**sthrn A**	**t & f**	**46**	**5**	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**Yes**	**No**
Aves	**Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t & f**	**10**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**Yes**
Aves	***Van Rensburg *et al*. (2011)**	**b**	**2011**	**SA**	**t & f**	**77**	**7**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Brachiopoda	Mead *et al*. (2011)	jp	2011	SA	m	1	4	Yes	Yes	Yes	Yes	No	No	No
Bryozoa	Robinson *et al*. (2005)	jp	2005	SA	m	2	1	No	No	No	Yes	No	No	No
Bryozoa	Griffiths, Robinson & Mead (2009)	b	2009	SA	m	2	2	No	Yes	No	Yes	No	No	No
Bryozoa	**Mead *et al*. (2011)**	**jp**	**2011**	**SA**	**m**	**6**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Bryozoa	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**m**	**6**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Ciliophora	Bruton & Merron (1985)	r	1985	sthrn A	f	2	1	Yes	No	No	No	No	No	No
Ciliophora	Bruton & Van As (1986)	b	1986	SA	f	2	0	No	No	No	No	No	No	No
Ciliophora	**De Moor & Bruton (1988)**	**r**	**1988**	**sthrn A**	**f**	**2**	**3**	**Yes**	**No**	**No**	**Yes**	**Yes**	**No**	**No**
Ciliophora	**Mead *et al*. (2011)**	**jp**	**2011**	**SA**	**m**	**2**	**1**	**No**	**No**	**No**	**Yes**	**No**	**No**	**No**
Cnidaria	Bruton & Merron (1985)	r	1985	sthrn A	f	1	1	Yes	No	No	No	No	No	No
Cnidaria	Bruton & Van As (1986)	b	1986	SA	f	1	0	No	No	No	No	No	No	No
Cnidaria	**De Moor & Bruton (1988)**	**r**	**1988**	**sthrn A**	**f**	**1**	**6**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**
Cnidaria	Robinson *et al*. (2005)	jp	2005	SA	m	4	3	Yes	Yes	No	Yes	No	No	No
Cnidaria	Griffiths, Robinson & Mead (2009)	b	2009	SA	m	4	3	No	Yes	Yes	Yes	No	No	No
Cnidaria	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**f & m**	**13**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Cnidaria	**Mead *et al*. (2011)**	**jp**	**2011**	**SA**	**m**	**15**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Crustacea	Bruton & Merron (1985)	r	1985	sthrn A	f & m	2	1	Yes	No	No	No	No	No	No
Crustacea	Bruton & Van As (1986)	b	1986	SA	f & m	2	0	No	No	No	No	No	No	No
Crustacea	De Moor & Bruton (1988)	r	1988	sthrn A	f & m	3	5	Yes	Yes	Yes	Yes	Yes	No	No
Crustacea	Robinson *et al*. (2005)	jp	2005	SA	m	15	3	Yes	Yes	No	Yes	No	No	No
Crustacea	Griffiths, Robinson & Mead (2009)	b	2009	SA	m	17	4	Yes	Yes	Yes	Yes	No	No	No
Crustacea	**Mead *et al*. (2011)**	**jp**	**2011**	**SA**	**m**	**33**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Crustacea	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t & f & m**	**36**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Dinoflagellata	**Mead *et al*. (2011)**	**jp**	**2011**	**SA**	**m**	**3**	**3**	**Yes**	**Yes**	**No**	**Yes**	**No**	**No**	**No**
Echinodermata	Robinson *et al*. (2005)	jp	2005	SA	m	1	1	No	No	No	Yes	No	No	No
Echinodermata	Griffiths, Robinson & Mead (2009)	b	2009	SA	m	2	3	No	Yes	Yes	Yes	No	No	No
Echinodermata	**Mead *et al*. (2011)**	**jp**	**2011**	**SA**	**m**	**2**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Echinodermata	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**m**	**2**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Insecta	Annecke & Moran (1982)	b	1982	SA	t	63	3	Yes	Yes	Yes	No	No	No	No
Insecta	Bruton & Merron (1985)	r	1985	sthrn A	f	4	1	Yes	No	No	No	No	No	No
Insecta	Deacon (1986)	b	1986	SA	t	1	1	No	Yes	No	No	No	No	No
Insecta	De Moor & Bruton (1988)	r	1988	sthrn A	f	5	7	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Insecta	Millar (1990)	b	1990	SA	t	68	2	No	Yes	Yes	No	No	No	No
Insecta	Vári, Kroon & Krüger (2002)	b	2002	sthrn A	t	25	1	Yes	No	No	No	No	No	No
Insecta	Visser (2009)	b	2009	SA	t	12	3	Yes	Yes	Yes	No	No	No	No

Notes: For each taxonomic group only references in bold were included in the full analysis. References with an asterisk (*) were identified by experts as the most comprehensive. **Publication type** (Type): b, book; jp, journal paper; r, report; **Region**: South Africa (SA); southern Africa (sthrn A); southern hemisphere (sthrn H); global (g); **Habitat covered** (Habitat): t, terrestrial; f, freshwater; m, marine; **Approximate number of listed alien taxa** (# Taxa); **Number of data types provided** (# Categories); **Whether data on pathway of introduction** (Path)**, date of introduction** (Date)**, region of origin** (Origin)**, distribution** (Distribution)**, invasion status** (Status)**, failure** (Failure) **and introduction effort** (Effort) **are provided**.

TABLE A2 continues on the next page →

TABLE A2 (Continued...): Results of the assessment of alien species databases.

Taxonomic group	Reference	Type	Year	Region	Habitat	# Taxa	# Categories	Path	Date	Origin	Distribution	Status	Failure	Effort
Insecta	**Mead *et al.* (2011)**	**jp**	**2011**	**SA**	**m**	**1**	**3**	**Yes**	**No**	**Yes**	**Yes**	**No**	**No**	**No**
Insecta	Giliomee (2011)	jp	2011	SA	t	13	2	Yes	Yes	No	No	No	No	No
Insecta	**Klein (2011)**	**jp**	**2011**	**SA**	**t**	**222**	**4**	**Yes**	**Yes**	**No**	**No**	**Yes**	**Yes**	**No**
Insecta	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t**	**287**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**Yes**
Mammalia	Bruton & Merron (1985)	r	1985	sthrn A	f	1	1	Yes	No	No	No	No	No	No
Mammalia	Lever (1985)	b	1985	g	t	10	5	Yes	Yes	Yes	Yes	No	No	Yes
Mammalia	Deacon (1986)	b	1986	SA	t	12	1	No	Yes	No	No	No	No	No
Mammalia	**Long (2003)**	**b**	**2003**	**g**	**t**	**39**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**Yes**
Mammalia	**Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t**	**13**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**Yes**
Mammalia	***Van Rensburg *et al.* (2011)**	**b**	**2011**	**SA**	**t**	**51**	**4**	**Yes**	**Yes**	**No**	**No**	**Yes**	**Yes**	**No**
Mollusca	Bruton & Merron (1985)	r	1985	sthrn A	f & m	7	1	Yes	No	No	No	No	No	No
Mollusca	Bruton & Van As (1986)	b	1986	SA	f & m	7	0	No	No	No	No	No	No	No
Mollusca	De Moor & Bruton (1988)	r	1988	sthrn A	f & m	6	5	Yes	Yes	Yes	Yes	Yes	No	No
Mollusca	**Appleton (2003)**	**jp**	**2003**	**SA**	**f**	**10**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**
Mollusca	Robinson *et al.* (2005)	jp	2005	SA	m	3	3	Yes	Yes	No	Yes	No	No	No
Mollusca	Griffiths, Robinson & Mead (2009)	b	2009	SA	m	5	4	Yes	Yes	Yes	Yes	No	No	No
Mollusca	Visser (2009)	b	2009	SA	t	8	2	Yes	No	Yes	No	No	No	No
Mollusca	***Herbert (2010)**	**b**	**2010**	**SA**	**t**	**36**	**6**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**Yes**
Mollusca	**Mead *et al.* (2011)**	**jp**	**2011**	**SA**	**m**	**21**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Mollusca	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t & f & m**	**51**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Myriapoda	Hamer (1998)	jp	1998	sthrn A	t	7	2	No	No	Yes	Yes	No	No	No
Myriapoda	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t**	**9**	**3**	**Yes**	**No**	**Yes**	**Yes**	**No**	**No**	**No**
Nematoda	**Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t**	**5**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Plantae	Poynton (1979b)	b	1979	sthrn A	t	77	6	Yes	Yes	Yes	Yes	No	Yes	Yes
Plantae	Poynton (1979a)	b	1979	sthrn A	t	200	6	Yes	Yes	Yes	Yes	No	Yes	Yes
Plantae	Von Breitenbach (1984)	b	1984	SA	t	741	0	No	No	No	No	No	No	No
Plantae	Deacon (1986)	b	1986	SA	t & f	18	1	No	Yes	No	No	No	No	No
Plantae	Richardson, Williams & Hobbs (1994)	jp	1994	sthrn H	t	11	1	No	Yes	No	No	No	No	No
Plantae	**Henderson (2001)**	**b**	**2001**	**SA**	**t & f**	**243**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**
Plantae	Richardson & Rejmánek (2004)	jp	2004	g	t	14	1	No	No	No	No	Yes	No	No
Plantae	Nel *et al.* (2004)	jp	2004	SA	t	204	0	No	No	No	No	No	No	No
Plantae	Robinson *et al.* (2005)	jp	2005	SA	m	3	2	No	Yes	No	Yes	No	No	No
Plantae	***Germishuizen *et al.* (2006)**	**b**	**2006**	**SA**	**t & f**	**978**	**1**	**No**	**No**	**No**	**Yes**	**No**	**No**	**No**
Plantae	Griffiths, Robinson & Mead (2009)	b	2009	SA	m	3	3	No	Yes	Yes	Yes	No	No	No
Plantae	Poynton (2009)	b	2009	sthrn A	t	252	7	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Plantae	**Bromilow (2010)**	**b**	**2010**	**SA**	**t & f**	**572**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**
Plantae	**Mead *et al.* (2011)**	**jp**	**2011**	**SA**	**m**	**10**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Platyhelminthes	Bruton & Merron (1985)	r	1985	sthrn A	f	1	1	Yes	No	No	No	No	No	No
Platyhelminthes	Bruton & Van As (1986)	b	1986	SA	f	1	0	No	No	No	No	No	No	No
Platyhelminthes	**De Moor & Bruton (1988)**	**r**	**1988**	**sthrn A**	**f**	**1**	**5**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**
Platyhelminthes	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t & f**	**6**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Porifera	Griffiths, Robinson & Mead (2009)	b	2009	SA	m	1	0	No	No	No	No	No	No	No
Porifera	**Mead *et al.* (2011)**	**jp**	**2011**	**SA**	**m**	**1**	**3**	**Yes**	**Yes**	**No**	**Yes**	**No**	**No**	**No**
Porifera	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**m**	**1**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Pycnogonida	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**m**	**1**	**2**	**No**	**No**	**Yes**	**Yes**	**No**	**No**	**No**
Pycnogonida	**Mead *et al.* (2011)**	**jp**	**2011**	**SA**	**m**	**1**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Reptilia	Bruton & Merron (1985)	r	1985	sthrn A	f	1	2	Yes	No	No	No	Yes	No	No
Reptilia	Bruton & Van As (1986)	b	1986	SA	f	1	0	No	No	No	No	No	No	No
Reptilia	De Moor & Bruton (1988)	r	1988	sthrn A	f	1	5	Yes	No	Yes	Yes	Yes	No	Yes
Reptilia	**Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**t & f**	**1**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Reptilia	***Van Rensburg *et al.* (2011)**	**b**	**2011**	**SA**	**t & f**	**3**	**6**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**Yes**
Tunicata	Robinson *et al.* (2005)	jp	2005	SA	m	4	2	No	Yes	No	Yes	No	No	No
Tunicata	Griffiths, Robinson & Mead (2009)	b	2009	SA	m	5	4	Yes	Yes	Yes	Yes	No	No	No
Tunicata	***Picker & Griffiths (2011)**	**b**	**2011**	**SA**	**m**	**9**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**
Tunicata	**Mead *et al.* (2011)**	**jp**	**2011**	**SA**	**m**	**18**	**4**	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**	**No**

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